

# KYANITE AND RELATED MATERIALS

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Kyanite, andalusite, and sillimanite are anhydrous aluminosilicate minerals with the same chemical formula ( $\text{Al}_2\text{SiO}_5$ ) but different crystal structures and physical properties. When calcined at high temperatures (in the 1,400° C to 1,500° C range for kyanite and andalusite and 1,550° C to 1,625° C for sillimanite), these minerals are converted to mullite ( $\text{Al}_6\text{Si}_2\text{O}_{13}$ ) and silica ( $\text{SiO}_2$ ) (Harben, 1999). During calcination, 1.0 metric ton (t) of aluminosilicate concentrate yields about 0.88 t of mullite. Synthetic mullite is made by heating mixtures of bauxite and kaolin or alumina and silica at about 1,550° C to 2,000° C (Roskill Information Services Ltd., 1990, p. 55). Mullite increases the fired strength, resistance to deformation under load, and thermal resistivity of refractories. Refractories are the largest end use of kyanite, andalusite, and synthetic mullite in the United States and worldwide.

Although company data are proprietary, Dickson (2003) has estimated U.S. kyanite output to be about 90,000 metric tons per year (t/yr), which would make the United States the world's largest producer of this mineral (table 3). South Africa continued to be the leading producing country of andalusite with an estimated 220,000 t in 2003. France produced an estimated 65,000 t of andalusite. Although China may be a producer of sillimanite, the U.S. Geological Survey (USGS) has not obtained official production data (Dickson, 2003). Using available data, India has been the predominant producer of sillimanite with an estimated 12,000 to 14,000 t/yr in recent years. There was no reported U.S. production of sillimanite.

## Production

Kyanite Mining Corp. operated two open pit mines in Buckingham County, VA, and beneficiated the ore into a marketable kyanite concentrate. The company had two calcining kilns at its Dillwyn, VA, facility for production of calcined kyanite (mullite). Reported U.S. production data collected by the USGS are withheld to avoid revealing company proprietary information. Based on Dickson's (2003) estimated U.S. kyanite production of about 90,000 t/yr and value of \$149 per metric ton, the estimated value of kyanite concentrate was calculated to be about \$13 million (before conversion to mullite). High-temperature sintered synthetic mullite, made from calcined bauxitic kaolin and sold under the trade name Mulcoa 70, was produced by C-E Minerals, Inc. near Americus, GA. Estimated U.S. production of synthetic mullite was about 40,000 t/yr; the corresponding estimated value was about \$9.7 million, based on a value of \$243 per metric ton (Dickson, 2003).

Piedmont Minerals Co., Inc. in Hillsborough, NC, mined a deposit containing andalusite combined with pyrophyllite and sericite. The company sells products containing blends of the three minerals to refractories and ceramics producers.

## Consumption

Andalusite expands irreversibly by about 6% when calcined and can therefore be used directly in refractories in its raw state. Kyanite increases in volume by 16% to 18% on calcining and can be used in its raw concentrate form in a refractory mixture to counteract the shrinkage on firing of other components, especially clays (Dickson, 2003). In other refractory applications, kyanite concentrate is calcined to mullite before being added to refractory mixes if the volume increase of the kyanite is not required in the mix (Roskill Information Services Ltd., 1990, p. 56).

Examples of refractories that contain andalusite, kyanite, and/or synthetic mullite include insulating brick, firebrick, kiln furniture, refractory shapes, and monolithic refractories (made of a single piece or as a continuous structure) including castables (refractory concrete), gunning mixes, mortars, plastics, and ramming mixes. The interlocking grain structure of kyanite and mullite gives added mechanical strength to refractories and other nonrefractory ceramic articles. Other end uses of kyanite and related materials include brake shoes and pads, electrical porcelain, floor and wall tile, foundry use, precision casting molds, sanitaryware, and other products (Kyanite Mining Corp., 2001<sup>§</sup>).

## Foreign Trade

The United States exported kyanite and synthetic mullite to countries in Europe, Latin America, the Pacific rim, and other areas. Most of the material imported into the United States in 2003 was from South Africa and was presumed to be andalusite (table 2). No U.S. imports of kyanite or sillimanite in 2003 were reported.

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<sup>§</sup>A reference that includes a section mark (§) is found in the Internet Reference Cited section.

## World Review

**South Africa.**—Andalusite Resources (Pty) Ltd., a new producer of andalusite, began production at its operation at Maroelefontein in Limpopo Province (formerly Northern Province). The company's initial product contains 57% to 58% alumina ( $\text{Al}_2\text{O}_3$ ) and less than 1% hematite ( $\text{Fe}_2\text{O}_3$ ) and has a particle size range of 0.5 to 3 millimeters (mm). A higher grade alumina and coarser product was planned for development. Andalusite Resources is a subsidiary of African Mineral, Trading and Exploration (Pty) Ltd., which itself was the former Hernic Exploration Co. (Pty) Ltd. Andalusite Resources is the only independent source of andalusite outside of the Imerys group. Imerys' grades of andalusite from Glomel, France, and Annesley, South Africa, contain 59% alumina and have a particle size of 4 to 8 mm (Industrial Minerals, 2003a).

## Outlook

According to a study by The Freedonia Group, Inc., if the turnaround in the U.S. steel industry can be sustained, then long-term prospects for refractories in general in the United States are for increased demand. The iron and steel market represents more than one-half of all refractory demand. The study notes that there has been significant consolidation in the U.S. refractories industry. Also, the decline in refractory consumption per unit of output, such as steel production, may largely have run its course (Grahl, 2003). For example, in the glass industry, refractory consumption was 15 kilograms per metric ton (kg/t) of glass produced in the 1950s, dropping to 5 kg/t of glass produced in 2000 (Semler, 2002).

Vesuvius Group S.A., a major refractories producer with its head office in Brussels, Belgium, like various other refractories producers, has experienced consolidation and integration. However, with greater stability in the United States and European steel industries, the company is looking at growth opportunities, such as China (Moore, 2003).

According to the International Iron and Steel Institute, China is the largest steel producer, with 220 million metric tons in 2003. The Chinese market is said to be very competitive, with hundreds of indigenous refractory producers, some of which are very modern, and with a mixture of state and private ownership (Moore, 2003). Refractories company RHI AG of Austria has a joint venture plant in China and plans to build a second plant. RHI is focusing on supplying the Chinese steel producers as well as the surrounding markets of the Asia/Pacific region. There is a trend toward more finished refractories coming from China; while there is a restrictive export license for many refractory raw materials, no restrictions are placed on finished products. This has driven Chinese producers toward value-added refractory products, rather than supplying crude mineral products (Industrial Minerals, 2003b).

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## GENERAL SOURCES OF INFORMATION

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TABLE 1  
PRICE OF KYANITE AND RELATED MATERIALS IN 2003

(Dollars per metric ton)

	Price
Andalusite, free on board, Transvaal, South Africa, 57% to 58% alumina, 2,000-metric-ton bulk lots	221-258
Kyanite, USA, ex-works, calcined (mullite), 54% to 60% alumina, 18-ton lots	262-295

Source: Industrial Minerals, no. 435, December 2003, p. 74.

TABLE 2  
U.S. IMPORTS FOR CONSUMPTION OF ANDALUSITE,  
KYANITE, AND SILLIMANITE<sup>1, 2, 3</sup>

Year	Quantity (metric tons)	Value <sup>4</sup> (thousands)
2002	4,620	\$952
2003	4,480	1,090

<sup>1</sup>Most material is andalusite from South Africa.

<sup>2</sup>Harmonized Tariff System (HTS) code 2508.50.0000.

<sup>3</sup>Data are rounded to no more than three significant digits.

<sup>4</sup>Customs value.

Source: U.S. Census Bureau.

TABLE 3  
KYANITE AND RELATED MINERALS: ESTIMATED WORLD PRODUCTION, BY COUNTRY<sup>1, 2</sup>

(Metric tons)

Country and commodity <sup>3</sup>	1999	2000	2001	2002	2003
Australia:					
Kyanite	1,000	1,000	1,000	1,000	1,000
Sillimanite <sup>4</sup>	100	100	100	300	300
Brazil, kyanite	600	600	600	600	600
China, unspecified	3,000	3,100	3,150	3,200	3,200
France, andalusite	70,000	65,000	65,000	65,000	65,000
India:					
Kyanite	5,000	5,000	5,500	6,000	6,000
Sillimanite	12,000	12,000	13,000	14,000	14,000
South Africa, andalusite	136,949 <sup>5</sup>	182,674 <sup>5</sup>	193,225 <sup>5</sup>	165,000 <sup>r, 5</sup>	220,000
Spain, andalusite	2,500	2,500	2,500	2,500	2,500
United States: <sup>6</sup>					
Kyanite	90,000	90,000	90,000	90,000	90,000
Mullite, synthetic	39,000	40,000	40,000	40,000	40,000
Zimbabwe, kyanite	4,000	10,970 <sup>5</sup>	9,682 <sup>5</sup>	5,657 <sup>r, 5</sup>	4,000

<sup>1</sup>Revised.

<sup>1</sup>U.S. and estimated data are rounded to no more than three significant digits.

<sup>2</sup>Owing to incomplete reporting, this table has not been totaled. Table includes data available through March 19, 2004.

<sup>3</sup>In addition to the countries listed, small amounts of kyanite were produced in Kenya in 2000; a number of other nations produce kyanite and related materials, but output is not reported quantitatively, and no reliable basis is available for estimation of output levels.

<sup>4</sup>In addition, about 7,000 metric tons per year of sillimanite clay (also called kaolinized sillimanite) that contains 40% to 48% Al<sub>2</sub>O<sub>3</sub> is produced.

<sup>5</sup>Reported figure.

<sup>6</sup>Source: Dickson, Ted, 2003, Sillimanite minerals, in Industrial minerals annual review supplement: London, United Kingdom, Mining Journal Ltd. CD-ROM.